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Synchronic and diachronic factors in the change from pre-aspiration to post-aspiration in Andalusian Spanish

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Abstract

The study is concerned with the mechanisms by which pre-and post-aspiration are related synchronically and diachronically in Andalusian Spanish. An analysis of isolated word productions by 24 speakers of a Western Andalusian and by 24 of an Eastern Andalusian variety each divided into two age groups provided evidence for a sound change in progress: younger speakers and those of the Western Andalusian variety were more likely to produce /st/ with a shorter pre-aspiration and with a longer post-aspiration phase than their older and Eastern Andalusian counterparts. The results of further between-group duration analyses show that the sound change cannot be entirely explained by a realignment from an anti-phase to an in-phase timing relationship between the closure and glottal opening; they also provide evidence for the development of a trading relationship between the duration of the closure and the duration of post-aspiration. In order to test whether perceptual factors might have contributed to this sound change, a perception experiment was carried out. Listeners of Argentinian Spanish judged stimuli of a minimal pair *pasta-pata* with variable pre-aspiration duration in a forced-choice perception test. When the continuum was synthesized with a slightly post-aspirated stop release, listeners were more inclined to perceive *pasta,* which suggests that post-aspiration is parsed with pre-aspiration and serves as a cue for the underlying /st/ even in a non-post-aspirating variety of Spanish.

Keywords

Pre-aspiration, /s/-aspiration, sound change, Andalusian Spanish, VOT

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1.0 Introduction

Aspiration is produced when the abduction of the vocal folds for a voiceless obstruent, typically a stop, is timed asynchronously with respect to the oral constriction and is anticipated/prolonged during the preceding/following sonorant. In the vast majority of languages in which aspiration occurs, it typically follows the obstruent release and the stop is said to be post-aspirated; but occasionally and much more rarely, languages have been shown to have pre-aspirated stops in which the aperiodic energy that characterises aspiration acoustically precedes the stop closure. In some languages, such as the Northern dialect of Icelandic, pre-aspirated stops are phonologically contrastive to post-aspirated stops word-medially (Helgason, 2002, 186), but in Southern Icelandic and in other cases there is phonetic variation between pre- and post-aspirated stops: thus Silverman (2003) presents examples of a Mexican language Tarascan (based on Foster, 1969) and of Gaelic (based on Borgstrøm, 1940) in which pre-aspirated and post-aspirated stops have a complementary distribution between word-medial and word-initial position respectively (see also Helgason, 2002, for an extensive review of the occurrence and distribution of pre-aspiration in the world's languages). The phonetic characteristics of pre-aspiration, compared to those of post-aspiration, are reported to be highly variable, both between the few languages in which it occurs and even within the same language group (Silverman, 2003). Its variability may come about because the conditions that have given rise to pre-aspiration historically are also varied: thus whereas pre-aspiration in Icelandic /hp ht hk/ has developed historically from Old Norse geminates /p: t: k:/ (Hansson, 2001; see also Stevens, 2010 for analogous developments in some Italian varieties), in some varieties of English, in which pre-aspiration has been shown to have a sociolinguistic function, it has been brought about predominantly as a result of pre-obstruent vowel devoicing (Docherty & Foulkes, 1999). The type of pre-aspiration in Andalusian Spanish that is the main focus of the present study has yet another origin which is due to the debuccalization of the fricative in /s/+voiceless stop sequences, a phenomenon known as */s/-aspiration,* either word-medially (*casco* [ˈkahko] ‘helmet’, *caspa* [ˈkahpa] ‘dandruff’, *pasta* [ˈpahta] ‘paste, pasta’) or across word boundaries (*las tapas* [lahˈtapah] ‘the lids’, *los perros* [loh ˈperoh] ‘the dogs’, *más caro* [mah ˈkaɾo] ‘more expensive’). /s/-aspiration is not limited to /s/+voiceless stops sequences in Andalusian Spanish but may affect any syllable final /s/ or /θ/ (e.g. *isla* [ˈihla] ‘island’; *capaz* [kaˈpah] ‘able’). Weakening of syllable-final fricatives is a common phenomenon in many languages, and aspiration as a result of voiceless fricative lenition is reported for a number of other languages and Romance dialects (see Solé, 2010, for an overview and an explanation based on an aerodynamic account).

/s/-aspiration occurs in numerous varieties of Spanish: For European Spanish it has been documented mainly in the south of Spain, but it has been shown recently that the phenomenon is extending to central varieties of Spain (Calero Fernández, 1993; Momcilovic, 2009). For American Spanish, /s/-weakening occurs in Caribbean and South American varieties such as Chilean and Argentinian Spanish and in some Central American dialects (see e.g. Canfield, 1981; Lipski, 1994, for an overview). Sociolinguistic and linguistic factors have also been shown to influence the realisation of coda-/s/. The weakening of /s/ typically occurs in a word-medial pre-consonantal position but it may also occur syllable-initially (e.g. *cinco centavos* [ˈsiŋko henˈtaβo] in Dominican Spanish, Jiménez Sabater, 1975, 77). There is considerable agreement that weakening comes about pre-consonantally and word-medially before it spreads to other contexts before vowels or pauses (Cedergren, 1978; Terrell, 1979; Terrell, 1981; Alba, 1990, Calero Fernández, 1993; Momcilovic, 2009, Samper Padilla, 2011). There is also considerable phonetic variation in syllable-final /s/-weakening in Spanish: it can be produced as a full alveolar fricative, or [h], or deleted, depending on phonological context (e.g. Alther, 1935; Marrero, 1990; Sánchez-Muñoz, 2004), social factors (e.g Cedergren, 1978; Lafford, 1986), and dialect.

For Andalusian Spanish, /s/-lenition is very common (Moya Corral, 1979; Carbonero Cano, 1982; Villena Ponsoda, 2008) and is presumed – as inferred from transcriber errors – to have existed since at least the 16th century (Lapesa, 1986; for a review see Romero, 1995b). In Western Andalusian Spanish (WAS), numerous variants of /sp, st, sk/ are possible including with pre-aspiration or breathy voicing, with closure lengthening, and with post-aspiration (Torreira 2007a, 2007b, 2012; O’Neill, 2010; Parrell, 2012). Although degree of post-aspiration was found to be affected by place of articulation (Torreira, 2012), results of Torreira (2007a, 2012) suggest post-aspiration occurs in all three stop types in Western Andalusian Spanish.

Torreira (2007a) acoustically analysed /sp, st, sk/ in three varieties of Spanish: Puerto Rican, Argentinian and Western Andalusian Spanish. He observed longer voice onset time (VOT) and shorter pre-aspiration for the Andalusian speakers, compared to the other two varieties. VOT was also longer in /sp, st, sk/ than in the respective singletons or /lC/ sequences in the Andalusian variety. Torreira (2007b) compared /sp, st, sk/ sequences of three Western Andalusian and three Castilian speakers (a variety in which /s/ is not aspirated) and found, as in Torreira (2007a), long post-aspiration for the Andalusian, but not for the Castilian speakers, and considerable variation in how pre-aspiration was realized. He concluded that post-aspiration in Andalusian Spanish was the result of coarticulation and extensive articulatory overlap, and proposed an on-going sound change from pre- to post-aspiration for the Andalusian variety.

For Eastern Andalusian Spanish (EAS), the phonological contrast /st, sk/ vs. /t, k/ seems not to depend on post-aspiration differences, but instead on either how the stop closure and preceding vowel duration are related or on the presence of pre-aspiration or breathy voice in /sC/ sequences (Gerfen, 2002). A study by O'Neill (2010) also found that, whereas in the two cities of Western Andalusia (Seville, Cádiz) /s/ + stop was realized with considerable post-aspiration, for those in Eastern Andalusia (Granada, Almería) a longer stop closure duration was found. Between 60 % (Granada) and 70 % (Seville) of intervocalic /p, t, k/ stops were found by contrast to have a voiced or partly voiced closure (O'Neill 2010, 33). Similar findings are reported in Torreira & Ernestus (2011) for /p, t, k/ in spontaneous Madrid Spanish. A further phenomenon that has been documented for Eastern Andalusian Spanish is the use of vowel lowering (and fronting in the case of /a/) in the context of /s/-lenition (e.g. *tienes* 'you have' [ˈtjɛnɛ]) which may be accompanied by vowel lengthening and/or vowel harmony (Narbona et al. 2003, 170; see Martínez Melgar, 1994 for a phonetic study of vowel harmony in Eastern Andalusian Spanish).

In a recent production study, Torreira (2012) tested if VOT increased with stress and decreased at slower speech rates in Western Andalusian Spanish just as it does in languages in which post-aspirated stops are phonemic (Kessinger & Blumstein, 1997). Neither speech rate nor lexical stress had a consistent effect on post-aspiration. Instead, Torreira (2012) observed a negative correlation between the combined duration of pre-aspiration and closure duration and the duration of post-aspiration; his conclusion from these results was that post-aspiration was more likely to be phonetic and the result of extensive articulatory overlap and not a principal cue to the /p, t, k/ vs. /sp, st, sk/ distinction (Torreira 2012, 61).

Several studies have suggested a sound change in progress in the Western variety of Andalusian Spanish by which pre-aspiration may be giving way to post-aspiration or affrication (Moya Corral, 2007; Torreira, 2007a, b; O'Neill 2010; Ruch, 2012). However, this question has not so far been addressed systematically. One of the main aims in this study is to assess whether in Andalusian Spanish there is a sound change in progress from pre- to post-aspiration. Parrell (2012) carried out a synchronic study of change in speech rate to test whether such a shift from pre- to post-aspiration can be expressed in terms of a model of gestural re-phasing between the open glottis and closure of the oral stop during /s/+voiceless stop clusters. According to this model which is inspired by articulatory phonology (Browman & Goldstein 1992; Goldstein et al. 2006), the synchronisation between glottal opening and the oral closure in producing pre-aspirated stops is anti-phase (because the oral closure is late in relation to the onset of the glottal opening in /st/ clusters), but it is in-phase in producing post-aspirated stops (in which the onset of glottal opening and the oral closure onset are synchronised).[1] Anti-phase timing relationships are in general more unstable than those that are in-phase not only in speech (Marin & Pouplier, 2010; Nam et al, 2010) but also in other types of skilled action, such as finger tapping (Kelso, 1984; Turvey, 1990): consequently, timing changes by which pre-aspiration changes to post-aspiration synchronically and diachronically should be probable, or more so than in the other direction in which timing relationships would be changed from in-phase to anti-phase. One of the main predictions of this model that is tested in both Parrell (2012) and Torreira (2012) is that the duration of pre- and post-aspiration should be inversely correlated as the coordination between the oral closure and glottal spreading switches from anti-phase to in-phase. Some evidence in support of this idea is provided in both of these studies: In Parrell's (2012) analysis of the /st/ cluster in *pastándola* ('grazing it') produced at different rates by 20 subjects, durational measurements of pre- and post-aspiration were found to be negatively correlated. Torreira (2012) found, as mentioned above, the duration of the combined pre-aspiration and stop closure to be negatively correlated with the duration of post-aspiration in productions of various /sp, st, sk/ clusters produced by three native speakers of Western Andalusian Spanish.

Our second aim in the present study is to assess whether this synchronic evidence for a change from an anti-phase to an in-phase timing relationship provided by Parrell (2012) can also be observed diachronically as inferred from comparisons between younger and older speakers of Andalusian Spanish on some of these measures. Another is to seek to resolve a controversy regarding closure duration in the course of this realignment between oral and glottal gestures. This issue is both controversial and unresolved because on the one hand, the closure duration is predicted to remain constant during changes to glottal-supraglottal coordination, as noted by Parrell (2012): “since the phase shift is independent of the duration of the gestures involved, there should be no changes in the oral constriction gesture itself”. On the other hand, the closure of /s/+voiceless stop clusters in Western Andalusian Spanish has been shown to be longer than both intervocalic stop closures of the same variety and longer than the closures that occur in /s/+voiceless stop clusters in other varieties of Spanish (Torreira 2007a). For Torreira (2012, 53), this finding of a lengthened closure provides a challenge for an explanation of pre- to post-aspiration change based entirely on phase relationships because it is “difficult to imagine how a delayed [h] glottal gesture in an [hp] cluster or a reduced and overlapped tongue-tip gesture in an [sp] cluster might lead to an online lengthening of the upcoming [p] closure produced at the lips”. Torreira (2012, 61) suggests that this lengthening of the supraglottal gesture may have arisen in order to “compensate for the realignment of [h] with respect to upcoming consonants”, and points to various studies that report lengthening of the consonant following an aspirated or deleted /s/ for Western Andalusian Spanish (e.g. Mondéjar, 1991, Romero, 1995a). However, longer closures in /st/-clusters than in intervocalic /t/ are also reported for the Eastern Andalusian variety by Gerfen (2002), and are described in dialectological studies not only for Andalusian /sp, st, sk/ (Alther, 1935, Alvar, 1955) but also for Cuban Spanish /s/+voiceless stop sequences (Ruiz Hernández & Miyares Bermúdez, 1984). It seems thus unlikely that the long stop closure in WAS is the result of compensation for the realignment with [h].

While Parrell (2012) notes that gestural re-phasing “does not predict any changes in the closure duration for the stop”, he nevertheless also suggests, referring to phonetic universals (Maddieson, 1997), that the closure duration might vary inversely with post-aspiration on the assumption that the duration of the glottal spreading gesture is invariant. Parrell’s (2012) results of the changes due to rate demonstrate just such a negative association between closure and post-aspiration duration. His findings are in line with Torreira (2007b) who also observed a negative (but not significant) correlation between VOT and closure duration for /sk/ and /st/, and attributed this relationship to universal articulatory constraints (such as aerodynamic factors or the constant duration of a glottal cycle: see Cho & Ladefoged, 1999). The negative correlation between closure duration and VOT is also not in line with Torreira's (2012) assumption of compensatory lengthening mentioned above.

Thus, there is evidently confusion about the durational changes to the closure as pre-aspiration wanes and post-aspiration increases given firstly the prediction that it should remain unchanged, secondly the demonstration by Torreira (2007a, b) of a long closure duration in Western Andalusian Spanish, and thirdly Parrell's (2012) other finding that the closure duration shortens as post-aspiration duration lengthens. In the present study, one of the aims will be to infer from our apparent-time investigation whether there is any evidence that the hypothetical diachronic change from pre- to post-aspiration in Andalusian Spanish /st/ clusters is associated with a change in the duration of the oral closure.

The attempts so far to explain the emergence of post-aspirated stops in Andalusian Spanish were all based on articulatory accounts. But there is also compelling evidence that the source of the synchronic instability leading to many types of diachronic change depends on auditory factors (Beddor, 2009; Ohala, 1993). According to perceptually-based models of sound change (Ohala, 1993), a post-aspirated release in the production of a pre-aspirated stop may lead to some confusion for the listener in the serial order of the aspiration and closure (see also Garrett & Blevins, 2004, for an interpretation of certain kinds of metathesis involving fricatives as due to a perceptual confusion in the serial order at which the fricative is produced in relation to the other segments). According to such a model, the emergence of post-aspiration might be perceptually confused with pre-aspiration and therefore interpreted as a (post-vocalic) underlying /s/.

In summary, there are three main aims of this study. The first is to compare younger and older speakers of Andalusian Spanish on the duration of pre- and post-aspiration in /st/ clusters in order assess whether there is a sound change in progress in this variety of Spanish (section 2). The second aim is to assess the plausibility of gestural re-phasing as the basis for the diachronic change from pre- to post-aspiration, and to test whether the synchronic change found by Parrell (2012) under fast speech by which pre-aspiration changes into post-aspiration (assuming minimal change to closure duration) might be the basis for the diachronic change (section 3). The third aim is to assess whether the lengthening of post-aspiration might have a perceptual basis (section 4).

The first two aims will additionally be tested in two separate but closely related varieties: Western Andalusian Spanish which is spoken in the provinces of Cádiz, Huelva, Málaga, and Seville; and Eastern Andalusian which is spoken in Almería, Córdoba, Granada, and Jaén (Mondéjar, 1991). The purpose of doing so was to provide an indication of the size of the diachronic change in the Western Andalusian variety, given that, with the possible exceptions of Moya Corral (1979) and O'Neill (2010), there are no reports either that /sp, st, sk/ are post-aspirated, nor that a change from pre- to post-aspiration is taking place in Eastern Andalusian Spanish.

2.0 The production of pre-aspiration and post-aspiration

2.1 Method

We recruited 48 subjects from Andalusia: 24 from the city of Seville, part of Western Andalusia, and 24 from the city of Granada, part of Eastern Andalusia. For each of these two varieties, there was a younger group (age range between 20-36 years) and an older group (age range 55-79 years). The four speaker groups – older and younger speakers of Western and Eastern Andalusia – were equally distributed in gender (six women and six men in each group), and, as far as possible, in educational level. All subjects of our study had lived for at least the last 20 years in their place of residence, Seville or Granada, with the exception of six speakers who lived in the nearby surrounding area of the respective city.

The materials included four isolated words that contained /st/ sequences and two words with /t/ stops that all occurred intervocalically in /e_a/ in trisyllabic words with lexical stress on the second syllable. The four /st/ sequences occurred in the words *estaba* (/esˈtaba/, 'to be', 1st/3rd person singular, imperfect past), *estado* (/esˈtado/, 'state'), *estanco* (/esˈtanko/, 'kiosk'), and *pestaña* (/pesˈtaɲa/, 'eyelash'); the two intervocalic /t/ stops in a matched vocalic context occurred in the words (henceforth /t/-

words) *etapa* (/eˈtapa/, 'period', 'stage') and *retara* (/reˈtaɾa/, 'to challenge', 1st/3rd person singular, past subjunctive). Each of these six words was repeated three times resulting in 6 (words) × 3 (repetitions) × 48 (speakers) = 864 /V_1(s)tV_2/ target word tokens. In addition to the 6 target words, there were 130 items containing intervocalic singleton stops, /sC/-sequences or stop clusters which were recorded for a related study, and 45 items for an independent project, which at the same time served as fillers for our study. Each of these 181 words was repeated three times in a randomised order, resulting in a total of 543 words for each speaker.

Subjects read each item displayed individually on a computer monitor at a constant rate which was fixed at just over 40 items per minute. The recordings were carried out with the SpeechRecorder software (Draxler & Jänsch, 2004), using a portable computer and a Cakewalk UA-25 EX CV 2 or M-Audio MobilePre USB device, and a headset microphone Beyerdynamic Opus 54.16-3. Whenever possible, the recordings were carried out in the phonetics laboratory of the University of Seville or in the radio studio of Granada University; if not, we looked for a quiet room in the subjects' residence or work place. At the beginning of the recordings, speakers were asked to speak in their dialect in a natural way and as if they were talking to a friend.

From these 864 /V_1(s)tV_2/ target items, 73 were discarded, either because the word had been incorrectly read (a different word was produced from the one that was displayed on the screen) or because of hesitations or false starts. A further 33 were discarded because V_1 was completely aperiodic so that no frames of pitch data could be calculated. For the remaining 758 /V_1(s)tV_2/ tokens, the speech data were digitized at 44100 Hz and initially segmented automatically with the Munich Automatic Segmentation System (MAuS; Schiel, 2004). The MAUS-segmentation was based on a broad phonetic transcription of the target words taking into account the typical Andalusian pronunciation forms (of e.g. [ehˈtaðo] for *estado*). The boundaries were then readjusted manually to provide segment boundaries for the onset of V_1 ($V_{1.i}$), the offset of V_2 ($V_{2.f}$) and the onset (c_i) and offset (c_f) of the /t/-closure. $V_{1.i}$ and $V_{2.f}$ were marked at the beginning and end of periodicity respectively by inspecting the waveform; c_i was marked, as judged from waveform and spectrographic displays, where the energy decreased clearly, and c_f was marked at the release of the target stop (Fig. 1). The aim of this procedure was to find a semi-automatic and gradient way to determine voice termination time (*VTT*) as a measure for pre-aspiration duration, and voice termination time (*VOT*) as a measure for post-aspiration duration.

Fig. 1 about here

Once these boundaries had been marked, two pitch trackers, one based on ESPS/waves and the other on Scheffers (1983), both of which are part of the Emu speech database system (Harrington, 2010), were used to calculate automatically the acoustic offset of V_1 ($V_{1.f}$) and the acoustic onset of V_2 ($V_{2.i}$). The acoustic offset of V_1 was marked at the calculated cessation of periodicity in frames of pitch data (interval 5 ms) working forwards in time between $V_{1.i}$ and c_f. A subsequent inspection of waveform/spectrographic displays showed that the ESPS/waves pitch-tracker was more reliable than the algorithm based on Scheffers (1983) for marking the cessation of periodicity when the voicing offset preceded c_i, the acoustic onset of the stop closure (i.e. in cases in which the stop closure was fully voiceless). But if periodicity extended into the closure, then the algorithm based on Scheffers (1983) more reliably detected when periodicity ceased (whereas the ESPS/waves pitch-tracker would often declare the entire closure to be voiced, even though there was no evidence of this from visual displays)[2]. Accordingly, $V_{1.f}$ was defined as the point at which periodicity ceased as calculated by the ESPS/waves pitch tracker if this time point preceded c_i, but otherwise from the pitch tracker based on Scheffers (1983). The onset of V_2 was calculated in an exactly analogous way but working backwards in time between $V_{2.f}$ and c_i.

Table I about here

Finally, the 368 tokens of /V_1stV_2/-words for which the /s/-duration was greater than zero (i.e. for which $c_i > V_{1.f}$) were auditorily classified by the first author of this paper according to whether the medial cluster was judged to have been produced in one of three ways: either as [st] (the first consonant was produced with an alveolar fricative); or as [ht] (the first consonant was lenited to [h]); or as [0t] (the first consonant was deleted). Our aim was to remove as many of the first category produced with an alveolar fricative as possible from further consideration using an automatic, acoustic technique. In order to do so, *k*-means clustering (Hartigan & Wong, 1979) was applied to the mean zero-crossing density calculated over the interval between $V_{1.f}$ and

c_i: the motivation for this parameter was that an alveolar fricative tends to have energy concentrated in a higher frequency range (as a result of which the zero-crossing density is higher) than pre-aspirated frication i.e. than frication from a lenited /s/. The desired output of the *k*-means clustering algorithm was that one group would contain /st/ sequences that had been judged auditorily to have been produced with an alveolar fricative; and that the other group derived from *k*-means clustering would contain predominantly the tokens auditorily labelled as [ht] or [0t]. As Table I shows, one of the two groups output from *k*-means clustering contained 54/75 tokens that we had auditorily classified as [s] and two tokens that we had not. These 56 tokens in this group were removed from further analysis.

Table II about here

The final breakdown of the remaining 702 tokens that were analysed in this paper is shown in Table II. We use henceforth the shorthand notation *ht*-words to refer to the remaining tokens produced for the large part with a lenited/aspirated /s/ in *estaba, estado, estanco, pestaña* (row 1 of Table II); and *t-words* to refer to *etapa* and *retara* (row 2 of Table II).

For all tokens in Table II, we defined voice termination time (*VTT*) as the duration between the cessation of periodicity in V_1 and the onset of the following closure i.e. $VTT = c_i - V_{1,f}$ (Fig. 1). *VTT* was typically (but not exclusively) positive in *ht*-words (i.e., periodicity ceased before the onset of the closure) whereas in *t*-words, *VTT* was close to zero or negative (voicing from V_1 extended into the closure). We defined voice onset time (*VOT*) also for all tokens in Table II as the duration between the offset of the closure and the onset of periodicity i.e. $VOT = V_{2.i} - c_f$. It turned out that for all tokens, *VOT* was positive.[3]

The results below are based on tests of whether *VTT* was smaller in younger speakers and *VOT* larger as a reflection of a sound change in progress by which pre-aspiration (as inferred from *VVT*) is waning and post-aspiration (as inferred from *VOT*) is increasing in *ht*-words in these two varieties of Andalusian Spanish. The hypothesis was also tested that the distinction between *ht*-words and *t*-words would be based for older speakers predominantly on *VTT* (on the assumption that they produced *ht*-words with long pre-aspiration) but for younger speakers on *VOT* (assuming that for them, *ht*-words were produced with long post-aspiration).

2.2 Results

We present the result separately for *VTT*, closure duration, and *VOT* below. The mean values and standard deviations on these parameters for the categories that were analysed are shown in Table III.

Table III about here

Fig. 2 about here

Fig. 2 shows both a larger *VTT* for older than younger speakers and that the *VTT*-difference between *ht*-words and *t*-words was larger for older speakers. A mixed model in R (R Development Core Team, 2012) was applied to all 702 tokens (Table II) with *VTT* as the dependent variable, with fixed factors age (old vs young), variety (Western vs Eastern Andalusian Spanish), and word-type (two levels: *ht*-words vs. *t*-words); and with the speaker (48 levels) and word (6 levels) as random factors. Since the three-way interaction between the fixed factors was not significant, it was removed from the model. This updated model without the three-way interaction then showed that *VTT* was significantly influenced by age ($\chi^2_3 = 20.7$, $p < 0.001$) and by word-type ($\chi^2_3=22.8$, $p < 0.001$); this second result comes about because, as is evident from Fig. 2, *VTT* was significantly larger in *ht*-words than in *t*-words. The influence of variety on *VTT* was not significant. The only two-way interaction that was significant was between age and word-type ($\chi^2_1 = 6.3$, $p < 0.05$): this result comes about because, as Fig. 2 shows, the difference in *VTT* between *ht*-words and *t*-words was larger for older than for younger speakers. This age-dependent influence on word-type was confirmed by multiple paired comparisons using alpha-adjusted Tukey-tests which showed that *VTT* was significantly larger for older than for younger speakers in *ht*-words ($z = 4.7$, $p < 0.001$), but not in *t*-words.

Fig. 3 about here

As Fig. 3 shows, closure duration was overall larger in *ht*-words than in *t*-words; and it was larger for older than for younger WAS speakers. Since a mixed model with the closure duration as the dependent variable and with the same fixed and random factors as for the *VTT*-analysis above showed that the three-way interaction was not significant, it was dropped from the model. The updated model without this three-way term showed a significant influence on closure duration of age ($\chi^2_3 = 13.1$, $p < 0.01$), variety ($\chi^2_3 = 22.4$, $p < 0.001$), and word-type ($\chi^2_3 = 38.1$, $p < 0.001$). There was also a significant interaction between age and word-type ($\chi^2_1 = 5.6$, $p < 0.05$) as well as between variety and word-type ($\chi^2_1 = 14.0$, $p < 0.001$) but not between age and variety. Paired comparisons using Tukey-tests showed that the closure duration was significantly larger in *ht*-words than in *t*-words for all four groups (older EAS: $z = 10.0$, $p < 0.001$; younger EAS: $z = 9.6$, $p < 0.001$; older WAS: $z = 8.5$, $p < 0.001$; younger WAS: $z = 6.0$, $p < 0.001$). They also showed that closure duration in *ht*-words (but not in *t*-words) was smaller for younger WAS speakers than for the other speaker groups (older WAS: $z = 3.2$, $p < 0.05$; younger EAS: $z = 3.6$, $p < 0.01$; older EAS: $z = 6.5$, $p < 0.01$). Thus this second set of results shows that, while a larger closure duration distinguished *ht*-words from *t*-words in all four groups, the difference in closure duration between these word-types was smaller for younger WAS speakers than it was for the other groups. For younger WAS speakers there was a trend (although not significant) to produce a shorter closure duration than older speakers also in *t*-words.

Fig. 4 about here

Finally Fig. 4 suggests that *VOT* was larger in younger than in older speakers and that the *VOT*-difference between *ht*-words and *t*-words was larger for younger than for older speakers. Since the mixed model with *VOT* as the dependent variable and with the same fixed and random factors as before showed significant three-way and two-way interactions between all combinations of the fixed factors, multiple paired comparisons using alpha-adjusted Tukey-tests were carried out. These showed that *VOT* was significantly larger in *ht*-words than in *t*-words in all speaker groups except for older EAS speakers (younger EAS: $z = 8.9$, $p < 0.001$; older WAS: $z = 4.3$, $p < 0.001$; younger WAS: $z = 19.3$, $p < 0.001$). The results of the mixed models also showed that *VOT* in *ht*-words (but not in *t*-words) was significantly larger for younger than for older speakers (younger vs. older EAS: $z = 4.8$, $p < 0.001$; younger vs. older WAS: $z = 9.1$, $p < 0.001$) and larger for younger WAS than for younger EAS speakers ($z = 6.4$, $p < 0.001$). Thus overall, and compatibly with the trends in Fig. 4, the results show that *VOT* was larger in *ht*-words than it was in *t*-words for all speaker-groups except for older EAS speakers; and that the *VOT*-difference between *ht*-words and *t*-words was (a) larger for younger than it was for older speakers and (b) larger for younger WAS speakers than for the other three groups.

2.3 Discussion

The findings show that Andalusian speakers made use of *VTT*, closure duration, and *VOT* for distinguishing *ht*-words from *t*-words. /t/-words showed mostly negative *VVT*, i.e. voicing extended into the closure, while /st/-words showed predominantly positive *VVT*, i.e. voicing ceased prior to the closure onset. This finding of partially voiced closures in Spanish intervocalic stops is consistent with Torreira & Ernestus (2011) for Madrid spontaneous speech, and with O'Neill (2010) for Andalusian Spanish. The idea that the closure may be long in Andalusian /s/+voiceless stop sequences is consistent both with the results from recent phonetic studies (Gerfen, 2002; Torreira, 2007a, b) as well as with earlier studies suggesting a geminate stop production in Andalusian Spanish /sp, st, sk/ (Alther, 1935; Alvar, 1955; see Torreira, 2012 for further examples and discussion of consonant lengthening in Western Andalusian Spanish); and it is also consistent with other evidence showing that pre-aspirated stops often seem to be accompanied by some form of strengthening of the following oral gesture in many languages (Silverman, 2003).

There was an effect of age on the analysed parameters such that *VTT* was smaller and *VOT* was larger for younger than for older speakers. To the extent that diachronic effects can be inferred from apparent-time data (Bailey et al, 1991; Weinreich et al, 1968), then this result suggests that there is a sound change in progress in Andalusian Spanish such that pre-aspiration is waning and post-aspiration is becoming more dominant as a cue for distinguishing intervocalic *s*-lenited/aspirated /st/ from intervocalic, singleton /t/.

There were two main influences of variety on this pattern of results: firstly, older EAS speakers in contrast to the other three speaker groups did not use *VOT* to distinguish *ht*-words from *t*-words; secondly, younger WAS speakers had the smallest closure duration and largest *VOT* of all four groups. The first of these results, combined with the finding of a larger *VOT* in younger WAS than in younger EAS speakers, is consistent with the idea that the sound change has progressed to a greater extent in the Western than in the Eastern variety. The second result may be indicative of a further innovation to the sound change produced by younger WAS speakers: with the progress of the sound change by which pre-aspiration gives way to post-aspiration, the duration of the closure also begins to shorten. [4]

If post-aspiration lengthening is accompanied by closure-shortening, then there should be evidence of a negative correlation between closure duration and *VOT* in *ht*-words, especially for the younger WAS group (which had the largest *VOT*). We tested whether there was any evidence for this in the next section. Another issue is whether there is compensatory lengthening, i.e. whether pre-aspiration shortening is correlated with closure lengthening. We also tested the idea from Parrell (2012) that post-aspiration arises as an increasing tendency to produce the glottal opening and the closure onset in phase. According to his model, post-aspiration arises because the oral closure of a constant duration is timed to occur earlier during the interval of glottal opening. If this is the case, then there should be a negative correlation between *VTT* and *VOT*, that is, a longer *VOT* should be accompanied by a shorter *VTT*.

3.0 The relative timing of pre-aspiration, closure, and post-aspiration

3.1 Method

The analysis was carried out for all tokens of *ht*-words (Table II). A mixed model was used to estimate the extent to which *VOT* could be predicted from a linear combination of either closure duration or *VTT* with variety and age as fixed factors and the speaker and word as random factors. The speaker was entered into the model in such a way to adjust both for the intercept and for the slope. The purpose of doing so was to be able to test not only whether there was a negative association between the numeric predictor (*VTT* or closure duration) and *VOT*, but also to explore whether the size of this effect differed across the four speaker groups.

3.2 Results

Fig. 5 about here

The results in Fig. 5 provide very little evidence of an inverse relationship between *VOT* and *VTT* within any of the speaker-groups; nor is there any suggestion that there was a larger inverse relationship between these parameters for younger vs. older speakers. Indeed the R^2 values for these data which vary between 0.0 (younger EAS) and 0.05 (older EAS) suggest that there was no linear relationship between these parameters. A mixed model in which the dependent variable *VOT* was predicted from *VTT* combined with age and variety as fixed factors and the speaker and word as random factors showed no evidence of any linear relationship between *VTT* and *VOT* ($\chi^2_3 = 3.0$, $p = 0.39$).

Fig. 6 about here

We then investigated whether any *VTT* or *VOT* changes were accompanied by changes in closure duration. Fig. 6 shows evidence for a negative relationship between *VTT* and closure duration among the older EAS speakers, but much less so for the other three speaker groups. Given that a mixed model with *VTT* as the dependent variable, closure duration, variety and age as fixed factors and word and speaker as random factors showed a significant interaction between the fixed factors, we re-ran the mixed models separately per speaker group. These results confirmed the trend observed in Fig. 6: there was a significant negative correlation between closure duration and *VTT* for older EAS speakers ($\chi^2_1 = 13.1$, $p < 0.001$), a very weak negative correlation for younger EAS speakers ($\chi^2_1 = 4.5$, $p < 0.05$) and no such negative correlation for WAS speakers.

Fig. 7 about here

The results in Fig. 7 show evidence for a negative relationship between *VOT* and closure duration: R^2 varied between 0.02 (older WAS) and 0.32 (younger WAS). The results of a mixed model in which *VOT* was predicted from closure duration combined with the same fixed and random factors as before showed a significant association between the two acoustic parameters ($\chi^2_3 = 35.0$, $p < 0.001$). We explored the group differences in this association by deriving from the mixed model 48 slopes (in the plane of closure duration × *VOT*), one for each speaker: that is, there is one slope per speaker derived from the linear association between closure duration and *VOT* calculated by the mixed model.

Fig. 8 about here

The results in Fig. 8 show, compatibly with the data in Fig. 7, that the slopes were negative for all four groups i.e. that there was a tendency for larger *VOT* to be associated with smaller closure durations. Fig. 8 also shows that this trend was in greater evidence for the younger than for the older speakers and to a lesser extent for EAS compared with WAS speakers. The results of an ANOVA with slope as the dependent variable (the 48 values, one per speaker, in Fig. 8) and with independent factors age and variety showed a significant effect for both factors (age: $F[1,44] = 51.8$, $p < 0.001$; variety: $F[1,44] = 18.0$, $p < 0.001$) and no significant interaction between these factors. Thus this second set of results shows that there was a negative association between *VOT* and closure duration; and that this negative association was more marked in younger than in older speakers, and more marked for Western than for Eastern Andalusian speakers.

3.3 Discussion

The results have shown that there was a greater negative correlation between closure duration and the duration of post-aspiration in the Western compared with the Eastern Andalusian variety and in younger than older speakers: this finding is consistent with Torreira (2007b) and Parrell (2012) who also found synchronic evidence for an association between closure duration shortening and post-aspiration lengthening. Our results suggest that the sound change is accompanied by the development of a trading relationship in which the group for which the sound change is most advanced, i.e. the younger speakers, produced words with an underlying /st/ sequence either with a long closure and short post-aspiration or with a short closure and a long post-aspiration. Older Eastern Andalusian speakers in contrast showed a negative relationship between *VTT* and closure duration, i.e. compensatory lengthening of the subsequent stop closure. Taken together, the results suggest that closure duration may co-vary either with pre- or with post-aspiration duration.

On the other hand, contrary to Parrell's (2012) model based on synchronic analyses of rate changes in *pastándola*, there is no evidence from the present apparent-time study of a correlation between the shortening of pre-aspiration and the lengthening of post-aspiration. Our findings suggest that post-aspiration lengthening is to a certain degree independent of pre-aspiration shortening, and that the former takes place gradually rather than categorically.

As an alternative to an explanation for post-aspiration lengthening and pre-aspiration shortening based on physiological timing relationships, we carried out a perception experiment. We tested how a slightly post-aspirated stop is perceived in varieties of Spanish that aspirate /s/ by carrying out a forced-choice perception experiment with listeners of Argentinian Spanish. The aim was to investigate how post-aspiration is parsed by listeners of a Spanish variety with pre-, but without post-aspiration. The general hypothesis to be tested was that in a continuum with a slightly post-aspirated stop (i.e. a longer VOT), listeners are more inclined to perceive /pasta/ than in a continuum with a short VOT because post-aspiration is parsed perceptually with pre-aspiration and therefore associated with the same underlying phonological /st/.

4.0 The influence of increasing post-aspiration on the perception of pre-aspiration

We synthesized two continua between /pasta/ and /pata/ in which pre-aspiration was shortened in nine steps; one continuum was synthesized with a slightly post-aspirated stop, the other one with a typical VOT for Spanish of 12 ms. The reason for carrying out the test with listeners of Argentinian Spanish is that words with medial /st/ are produced with /s/-lenition in most regions of Argentina (Aleza Izquierdo & Enguita Utrilla, 2002; i.e. *pasta* is realized as [pahta]); however, in contrast to Andalusian Spanish there is no evidence of a sound change in progress (such that pre-aspiration is giving way to post-aspiration) which could itself bias the perceptual responses towards /pasta/ (see Torreira 2007a for a comparison between WAS, Buenos Aires Spanish, and Puerto Rican Spanish).

The aim of this experiment was to simulate a situation similar to the one in Andalusian Spanish at the initiation of the sound change. The idea was to test whether there is a perceptual basis to the sound change from pre-aspiration to post-aspiration.

4.1 Method

4.1.1 Synthetic stimuli

A token of *pasta* produced by a younger WAS male speaker was selected from the corpus described in 2.1. The selected token had a long *VTT* (57 ms), a *VOT* of comparable duration (45 ms), and a closure duration of 139 ms. Since the second vowel of this token was weak and devoiced it was replaced by a stronger, fully voiced /a/ taken from the second vowel of a /pata/ token produced by the same speaker (the cut for the replacement was made at $V_{2.i}$ in Fig. 1). Subsequently, and in order to make pre- and post-aspiration durations more similar to the durations found in the production data of the EAS speakers (section 2.2) and the durations found by Torreira (2007a) for Argentinian Spanish, *VOT* was shortened to 29 ms, closure duration to 100 ms, and *VTT* to 34 ms. This was done by shortening proportionally the whole *VOT* (closure, or *VTT*) interval using PSOLA techniques and the Akustyk plugin (Plichta, 2012) in Praat (Boersma 2012). The resulting token with a *VTT* of 34 ms, a closure duration of 100 ms, and a *VOT* of 29 ms served as the base-word from which all other stimuli were derived.

In order to create the *long*-continuum, we reduced this base-word's *VTT* in nine equal steps from 34 ms to 0 ms using Akustyk, creating ten stimuli which differed only in *VTT* (i.e. pre-aspiration duration). The *short*-continuum was generated by copying the ten stimuli of the *long*-continuum and by substituting the *VOT* interval in every token by a shortened *VOT* of 12 ms at the $V_{2.i}$ cut point in Fig. 1. Through this procedure, we obtained two *VTT*-continua which differed only in the *VOT* of the stop release (*long* vs. *short*). A summary of all stimuli used in the perception experiment is shown in Table IV.

Table IV about here

4.2.2 Subjects

64 native speakers of Argentinian Spanish – 39 women and 25 men aged between 13 and 64 years (median: 26 years) – participated in the experiment. 25 subjects were born and raised in Santa Fe, 17 in Buenos Aires province, eight in the city of Buenos Aires and eight in Mendoza. The remaining six subjects were born and raised in other provinces of Argentina (Córdoba, Chaco, San Juan and Misiones). None of the

participants reported any hearing difficulties. Subjects were recruited via contact persons of the first author and by word of mouth and social media.

4.2.3 Procedure

The 20 stimuli shown in Table IV were repeated seven times, which gave a total number of 10 (steps) × 2 (continua) × 7 (repetitions) = 140 stimuli, and were presented as a web-based experiment using the software Percy (Draxler, 2011). Stimuli were played to the subjects in a randomized order and an auditory mode. After each stimulus was presented, the subject had to decide whether the word sounded more like 'pata' or 'pasta' by clicking one of two choices (denoting the words *pata* and *pasta* in orthographic form on the screen). There was no time pressure to complete the task and subjects could listen to each stimulus up to two times. All subjects were asked to wear headphones or earphones and to do the experiment in a quiet place. 58 participants reported having worn ear- or headphones one had used external loudspeakers, and five only the built-in speakers of the computer or laptop.

4.3 Results

Fig. 9 about here

We began by testing whether voice onset time (*short* = 12 ms vs. *long* = 29 ms) had an influence on the listeners' responses. Figure 9 shows the proportion of *pasta*-judgements according to continuum (*short* vs *long*) and *VTT* step (0 ms … 34 ms). It is apparent that there were more *pasta*-answers in the *long*- compared to the *short*-continuum for the stimuli with a short *VTT*, and that the proportion of *pasta*-answers increased with a longer *VTT* in the stimulus. Consistently with this trend in Fig. 9, the results of a generalised linear mixed model (GLMM) with the listener's response (*pata* or *pasta*) as the categorical dependent variable and with fixed factors continuum (two levels: *long* vs *short*) and stimulus number (ten levels: 0 … 9) and with the subject as random factor showed that the responses were significantly influenced by *VOT* ($z = 9.0$, $p < 0.001$) and stimulus number ($z = 16.1$, $p < 0.001$). The interaction between these factors ($z = 4.8$, $p < 0.001$) shows consistently with Fig. 9 that the *long*/*short* difference was more pronounced when *VTT* was short.

We then derived the psychometric curves and listener-specific slopes and intercepts from the GLMM.[6] These slopes and intercepts were used to obtain 50% decision boundaries separately for each listener. For seven out of 64 subjects no decision boundary (i.e. category boundary) within the stimuli range (i.e. between 0 and 9) was obtained: these subjects showed a strong tendency towards *pasta*-responses even in the stimuli with short pre-aspiration (and such that two of these responded with *pasta* for all stimuli). The data of these seven subjects were removed and excluded from further analysis.

Fig. 10 about here

Fig. 10 shows the averaged psychometric curves according to continuum (*long* vs. *short*) of the remaining 57 listeners. The psychometric curves show evidence of categorical perception and, consistent with our hypothesis, a greater proportion of *pasta*-responses in the *long*-continuum.

Fig. 11 about here

Fig. 11 shows negative values for the difference between the decision boundaries for most of the listeners: that is, the decision boundary was lower in the *long*- compared to the *short*-continuum. A paired-sample t-test with the data in Fig. 11 as the dependent variable confirmed significant differences on the decision boundaries between the two continua ($t = 5.6$, $df = 56$, $p < 0.001$). [6]

4.4 Discussion

In a [ˈpahta] stimulus with an aspirated stop release, listeners of Argentinian Spanish were more inclined to perceive *pasta* than in a stimulus which was acoustically identical with a shorter *VOT*. The results indicate that post-aspiration serves as cue for /st/ in a minimal pair *pata*-*pasta* also in a variety such as Argentinian Spanish in which /s/+voiceless stops are usually realized with pre- but not with post-aspiration. These results further suggest that the emerging post-aspiration is parsed with pre-aspiration and is perceptually associated with the underlying phonological /st/.

5.0 General discussion

One of the main aims of this paper has been to assess whether there is any evidence for a sound change in progress from pre- to post-aspiration in the production of intervocalic, word-medial /st/ sequences in Andalusian Spanish. The results of this apparent-time study with 48 speakers in two varieties of Andalusian Spanish have consistently with synchronically based studies (Torreira 2007a, 2007b, 2012; O'Neill 2010, 2010; Parrell, 2012) provided evidence that younger Western Andalusian speakers both produce pre-aspiration with a shorter and post-aspiration with a greater duration than older speakers from the same variety (section 2.3, Figs. 2 and 4). One of the new findings to emerge from this study is that there are similar, but less marked, age-dependent differences for Eastern Andalusian Spanish.

Another aim of this study has been to test the extent to which the diachronic changes can be explained by a categorical shift from an anti-phase to an in-phase alignment between the closure and glottal opening that has been suggested as characteristic of the change from slow to fast speech (Parrell, 2012). The present results (section 3.2, Figs. 5-7) suggest that this mechanism alone may be unable to account for the observed differences between the age groups and the varieties because firstly there was no significant co-variation between the duration of pre- and post-aspiration; and secondly, because closure duration was found to be less for younger than for older and for Western than Eastern Andalusian speakers in words with underlying intervocalic /st/, but not in those with underlying intervocalic /t/ (section 2.2, Fig. 3). Both of these findings run counter to a model in which the increase in post-aspiration is brought about by sliding a closure of constant duration towards the onset of glottal opening. The lack of a co-variation between *VTT* and *VOT* suggests a somewhat looser coupling between the duration of pre- and post-aspiration than has been found for the synchronic investigations of rate changes (Parrell, 2012), and it suggests that post-aspiration may increase independently of pre-aspiration shortening. Such an alternative model is further supported by the fact that variety influenced post-aspiration length but not the duration of pre-aspiration.

However, if we consider that articulatory and aerodynamic constraints can influence the duration or the oral closure (Cho & Ladefoged, 1999, 212-213), the finding of a variable closure duration does not, of course, necessarily contradict the phasing-model by Parrell (2012). A physiological study is required in order to better understand the timing of the glottal opening with the oral gesture in Andalusian Spanish, the constraints to this coordination, and the relationship between articulatory gestures and the acoustic signal.

Although the results were not consistent with the idea of an inverse relationship between the length of pre- and post-aspiration, there was, by contrast, evidence of such a relationship between the length of closure and post-aspiration in the younger speakers, and between length of closure and pre-aspiration in the older Eastern Andalusian speakers. These results suggest that intervocalic underlying /st/ was, prior to the development of post-aspiration lengthening (i.e. in older EAS speakers), distinguished from intervocalic /t/ by a long pre-aspiration combined with a relatively long closure, or by a short pre-aspiration combined with a long closure duration. This finding is in line with older dialectological studies (Alther 1935, Alvar 1955) that report lengthened stops in varieties of Andalusian Spanish for underlying /s/+voiceless stop sequences. According to our data, compensatory lengthening must have arisen *prior* to the emergence of post-aspiration (in contrast to Torreira's (2012) suggestion, see p. 9). During the sound change in progress, the distinction comes instead to be based on either a long closure combined with short post-aspiration or on a shortened closure combined with long post-aspiration. In several languages, pre-aspiration is reported to vary with either the duration of the preceding vowel, or with lengthening of the upcoming consonant (see Silverman, 2003, for examples and references). In the Algonquian language Ojibwa, for instance, geminates seem to have developed from pre-aspirated stops (Bloomfield 1963, 88). In our Eastern Andalusian data, there was evidence for compensatory lengthening, and for co-variation between pre-aspiration duration and closure duration. This type of synchronic variation thus parallels developments in languages with phonological pre-aspiration such as the above mentioned Ojibwa.

For the younger Andalusian speakers, the lengths of the oral closure and post-aspiration have entered into a trading relationship. It is possible that this type of trading relationship characterises certain types of sound change by which one of two cues that trade with each other eventually becomes progressively more dominant (see e.g. Beddor, 2009 for the relationship between cue trading and the development of phonological vowel nasalization in French). A consequence of the trading relationship in the present data is that, since a long post-aspiration implies a short closure then, if post-aspiration were to lengthen further (with the implication that the closure duration with which it trades would shorten even more), post-aspiration on its own may eventually become the primary cue for distinguishing intervocalic /st/ from intervocalic /t/ in Andalusian Spanish.

The results of the third part of this study support a perceptual model of the Andalusian sound change from pre- to post-aspiration. Argentinian listeners were more inclined to perceive *pasta* in a VTT-continuum synthesized with a longer VOT. This lends support to the idea that listeners of a non-post-aspirating variety of Spanish parse a (short) post-aspiration with the aspiration that precedes the stop (i.e. the pre-aspiration resulting from /s/-lenition). The longer VOT therefore is not perceived as a (deviant) variant of /pata/ but it enhances the perceptual cues for /st/. This finding is consistent with the idea of auditory theories and empirical evidence that propose speech is perceived as a whole pattern, and that the temporal order of segments in fluent speech cannot be reconstructed exactly by the listener (Warren, 2006). A parallel can be drawn between these results and the distribution of pre- and post-aspirated stops in the world's languages: There is no report of any language with a phonological contrast between pre- and post-aspirated stops (Clayton 2010, 64). In those languages that have both pre- and post-aspirated stops, they occur in complementary distribution: post-aspirated in word-initial, pre-aspiration in word-medial or word-final position. In Southern Icelandic, pre- and post-aspirated stops are nearly contrastive but co-occur with a different vowel quantity (a long vowel preceding post-aspirated stops, a short preceding pre-aspirated stops, Thráinsson 1978, 24).

Argentinians' perceptual responses to these long VOT stimuli are likely to be representative of the initial stages of the sound change from pre- to post-aspiration. More specifically, the evidence that Western and Eastern Andalusian varieties differ in post- but not pre-aspiration duration suggests that it is VOT lengthening or reinforcement that initially brought about the sound change. This greater VOT in speech production may then have come to be parsed perceptually with /st/.

The question of why the slightly longer VOT in *ht*-words compared to *t*-words arises has to remain an issue for future investigations. Physiological studies with speakers of a non-post-aspirating variety such as Argentinian Spanish or older Eastern Andalusians could shed light on this issue. A further unresolved question is how the slightly longer VOT spreads through the speech community and how it increases gradually over time. One possibility is that the slightly longer post-aspiration as produced by older Western Andalusians is imitated by other speakers. It has recently been shown that speakers of English produce a longer VOT after having been exposed to speech with long VOT (e.g. Sancier & Fowler, 1997; Nielsen, 2011).

In conclusion, the condition that gives rise to this sound change is likely to be post-aspiration lengthening which perceptually comes to be parsed with /st/. A further development in this sound change is the progressive attrition of the closure in words with underlying /st/, as post-aspiration lengthens. It is possible that the initially long geminate-like closure in underlying /st/ clusters (before the sound change took hold) may have created the conditions for air-pressure to rise leading to a prominently released /t/: but this speculative suggestion requires further physiological and perceptual investigation.

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Reference List

Alba, O. (1990). *Variación fonética y diversidad social en el español dominicano de Santiago*. Santiago: Pontificia Universidad Católica Madre y Maestra.

Aleza Izquierdo, M. & Enguita Utrilla, J. M. (2002). *El español de América: aproximación sincrónica*. Valencia: tirant lo blanch.

Alther, A. (1935). *Beiträge zur Lautlehre südspanischer Mundarten*. PhD dissertation, Universität Zürich.

Alvar, M. (1955). Las hablas meridionales de España y su interés para la lingüística comparada. *Revista de Filología Española* 39, 284–313.

Bailey, G; Wikle, T.; Tillery, J.; Sand, L. (1991). The apparent time construct. *Language Variation and Change* 3, 241-264.

Beddor, P. S. (2009). A coarticulatory path to sound change. *Language* 85.4, 785-821.

Bloomfield, L. (1963). Algonquian. In H. Hoijer (eds), *Linguistic Structures of Native America*, Johnson Reprint Corporation, Berkeley, 85–129.

Boersma, P., & Weenink, D. (2012). *Praat: Doing phonetics by computer* (Version 5.3.04) [Computer program]. Retrieved January 12, 2012, from /http://www. praat.org/S.

Borgstrøm, C. (1940). *The dialects of the Outer Hebrides* (A linguistic survey of the dialects of Scotland, vol. 1; Norsk Tidsskrift for Sprogvidenskap, Supp. Bind 1). Oslo: Norwegian Universities Press.

Browman, C. P., & Goldstein, L. (1992). Articulatory Phonology: An Overview. *Phonetica*, 49, 155-180.

Calero Fernández, M. Á. (1993). *Estudio sociolingüístico del habla de Toledo*. Lleida: Pagès Editors.

Canfield, L. (1981). *Spanish Pronunciation in the Americas*. Chicago: University of Chicago Press.

Carbonero Cano, P. (1982). *El habla de Sevilla*. Sevilla: Servicio de Publicaciones del Ayuntamiento de Sevilla.

Cedergren, H. (1978). En torno a la variación de la s final de sílaba en Panamá: Análisis cuantitativo. In H. López Morales (ed.). *Corrientes actuales en la dialectología del Caribe*. Hato Rey: Ediciones de la Universidad de Puerto Rico, 35–50.

Cho, T. & Ladefoged, P. (1999). Variation and universals in VOT: evidence from 18 languages. *Journal of Phonetics* 27, 207–229.

Clayton, I. (2010). *On the Natural History of Preaspirated Stops*. Unpublished PhD thesis, University of North Carolina, Chapel Hill.

Docherty, G. J. & Foulkes, P. (1999). Newcastle upon Tyne and Derby: instrumental phonetics and variationist studies. In P. Foulkes & G. Docherty (eds.), *Urban voices*. London: Edward Arnold. 47–71.

Draxler, C. & Jänsch, K. (2004). SpeechRecorder - A universal platform independent multichannel audio recording software. In *Proceedings of the Fourth International Conference on Language Resources and Evaluation*, Lissabon, Portugal, 559–562.

Draxler, C. (2011). Percy - an HTML5 framework for media rich web experiments on mobile devices. *Proceedings of Interspeech*, Florence, Italy, 3339-3340.

Foster, Mary LeCron (1969). *The Tarascan language*. University of California Publications Linguistics 56. Berkeley & Los Angeles: University of California Press.

Garrett, A. & Blevins, J. (2004) The evolution of metathesis. In B. Hayes, R. Kirchner, and D. Steriade (eds.), *Phonetically-based Phonology*. Cambridge University Press: Cambridge, 117-156.

Gerfen, C. (2002). Andalusian Codas. *Probus* 14, 247-277.

Goldstein, L., D. Byrd, & E. Saltzman (2006). The role of vocal tract gestural action units in understanding the evolution of phonology. In M. Arbib (ed.), *From action to language: The mirror neuron system*. Cambridge: Cambridge University Press, 215-249.

Hansson, G. (2001). Remains of a submerged continent: preaspiration in the languages of Northwest Europe. In L. Brinton (ed.), *Historical Linguistics 1999*, Amsterdam: John Benjamins, 157-73.

Harrington, J. (2010). *Phonetic analysis of speech corpora*. Malden MA: Wiley-Blackwell.

Hartigan, J. & Wong, M. (1979). Algorithm AS 136: a k-means clustering algorithm, *Journal of the Royal Statistical Society, Series C (Applied Statistics)* 28(1), 100–108.

Helgason, P. (2002). *Preaspiration in the Nordic Languages: Synchronic and Diachronic Aspects*. Doctoral Thesis, Stockholm University.

Jiménez Sabater, M. (1975). *Más datos sobre el español de la República Dominicana*. Santo Domingo: Ediciones intec.

Kelso, J. A. S. (1984). Phase transitions and critical behavior in human bimanual coordination. *American Journal of Physiology – Regulatory, Integrative and Comparative Physiology*, 246(6), R1000–R1004.

Kessinger, R. H. & Blumstein, S. E. (1997). Effects of speaking rate on voice-onset time in Thai, French, and English. *Journal of Phonetics* 25, 143–168.

Lafford, B. A. (1986). Valor diagnóstico-social del uso de ciertas variantes de /s/ en el español de Cartagena, Colombia. In R. A. Núñez Cedeño (ed.), *Estudios sobre la fonología del español del Caribe*, Caracas: Ediciones La Casa de Bello, 53–74.

Lapesa, R. (1986). *Historia de la lengua española,* Gredos, Madrid.

Lipski, J. M. (1994). *Latin American Spanish*. London and New York: Longman.

Maddieson, I. (1997). Phonetic Universals. In J. Laver, & W. J. Hardcastle (eds.), *The handbook of phonetic sciences*, Oxford: Blackwell, 619–639.

Marin, S., & Pouplier, M. (2010). Temporal organization of complex onsets and codas in American English: Testing the predictions of a gestural coupling model. *Motor Control,* 14(3), 380-407.

Marrero, V. (1990). Estudio acústico de la aspiración en español. *Revista de Filología Española* 70(3/4), 345–397.

Martínez Melgar, A. (1994). El vocalismo del andaluz oriental. *Estudios de Fonética Experimental* 6, 12–64.

Momcilovic, N. B. (2009). *A sociolinguistic analysis of /s/-aspiration in Madrid Spanish*. München: LINCOM Studies in Romance Linguistics.

Mondéjar, J. (1991), *Dialectología andaluza*, Málaga: Universidad de Málaga.

Moya Corral, J. A. (1979). *La pronunciación del español en Jaén.* Granada: Universidad de Granada.

Moya Corral, J. A. (2007). Noticia de un sonido emergente: la africada dental procedente del grupo -st- en Andalucía. *Revista de Filología de la Universidad de La Laguna* 25, 457–465.

Nam, H., Goldstein, L., & Saltzman, E. (2010). Self-organization of syllable structure: A coupled oscillator model. In F. Pellegrino, E. Marisco, & I. Chitoran (eds.), Approaches to phonological complexity. Berlin/New York: Mouton de Gruyter, 299–328.

Narbona, A., Cano, R. & Morillo, R. (2003). *El español hablado en Andalucía*. Sevilla: Fundación José Manuel Lara.

Nielsen, K. (2011). Specificity and abstractness of VOT imitation. *Journal of Phonetics* 39(2), 132–142.

Ohala, J. (1993). Sound change as nature's speech perception experiment. *Speech Communication* 13, 155-161.

O'Neill, P. (2010). Variación y cambio en las consonantes oclusivas del español de Andalucía. *Estudios de Fonética Experimental* XIX, 11–41.

Parrell, B. (2012). The role of gestural phasing in Western Andalusian Spanish Aspiration. *Journal of Phonetics* 40, 37-45.

Plichta, B. (2012). Akustyk. Version 1.9. URL: http://bartus.org/akustyk/.

R Development Core Team (2011). *R: A language and environment for statistical computing*. URL: http://www.R-project.org.

Romero, J. (1995a). *Gestural organization in Spanish: An experimental study of spirantization and aspiration*. PhD dissertation, University of Connectitut.

Romero, J. (1995b). An articulatory view of historical S-aspiration in Spanish. *Haskins Laboratories Status Report on Speech Research* 119/120, 255–266.

Ruch, H. (2012). Affrication of /st/ in Western Andalusian Spanish: Variation and change from a sociophonetic point of view. In S. Calamai, C. Celata, L. Ciucci (eds.), *Proceedings of "Sociophonetics, at the crossroads of speech variation, processing and communication"*, Pisa, December 14th-15th, 2010. Pisa: Edizioni della Normale, 61-64.

Ruiz Hernández, J. V. & Miyares Bermúdez, E. (1984). *El consonantismo en Cuba*. La Habana: Editorial de Ciencias Sociales.

Samper Padilla, J. A. (2011). Sociophonological variation and change in Spain. In M. Díaz Campos (ed.), *Handbook of Hispanic Sociolinguistics*. Oxford: Blackwell, 98–120.

Sancier, M. & Fowler, C. (1997). Gestural drift in a bilingual speaker of Brazilian Portuguese and English. *Journal of Phonetics* 25, 421–436.

Scheffers, M. T. (1983). Simulation of auditory analysis of pitch: An elaboration of the DWS pitch meter, *Journal of the Acoustical Society of America* 74(6), 1716–1725.

Schiel, F. (2004). MAuS goes iterative. In *Proceedings of the Fourth International Conference on Language Resources and Evaluation*, Lissabon, 1015–1018

Silverman, D. (2003). On the rarity of pre-aspirated stops. *Journal of Linguistics* 39, 575-598.

Solé, M.J. (2010). Effects of syllable position on sound change: An aerodynamic study of final fricative weakening. *Journal of Phonetics* 38/2: 289-305.

Stevens, M. (2010). How widespread is preaspiration in Italy? A preliminary acoustic phonetic overview. In S. Schötz and G. Ambrazaitis (eds.), *Working Papers of the Department of Linguistics and Phonetics 2010*, Lund University: 97-102.

Talkin, D. (1995). A robust algorithm for pitch tracking (RAPT). In W. Klein & K. Paliwal (eds.), *Speech Coding and Synthesis*, Elsevier: Amsterdam, 495-518.

Terrell, T. (1979). Final /s/ in Cuban Spanish. *Hispania* 62, 599–612.

Terrell, T. (1981). Diachronic reconstruction by dialect comparison of variable constraints: s-aspiration and deletion in Spanish. In D. Sankoff & H. Cedergren (eds.), *Variation Omnibus*, Edmonton, Canada: Linguistic Research Inc., 115–124.

Thráinsson, H. (1978). On the phonology of Icelandic preaspiration. *Nordic Journal of Linguistics* 1, 3–54.

Torreira, F. (2007a). Coarticulation between aspirated-s and voiceless stops in Spanish: an interdialectal comparison. In N. Sagarra & A. J. Toribio (eds.), *Selected Proceedings of the 9th Hispanic Linguistics Symposium*, Somerville MA: Cascadilla Proceedings Project, 114-120.

Torreira, F. (2007b). Pre- and postaspirated stops in Andalusian Spanish. In P. Prieto, P. Mascaró & M.-J. Solé (eds.), *Segmental and prosodic issues in Romance Phonology*, Benjamins, Amsterdam, 67–82.

Torreira, F. (2012). Investigating the nature of aspirated stops in Western Andalusian Spanish. *Journal of the International Phonetic Association* 42/1, 49-63.

Torreira, F. & Ernestus, M. (2011). Realization of voiceless stops and vowels in conversational French and Spanish. *Laboratory Phonology* 2, 331–353.

Turvey, M. T. (1990). Coordination. *American Psychologist,* 45, 938-953.

Villena Ponsoda, J. A. (2008). Sociolinguistic patterns of Andalusian Spanish. *International Journal of the Sociology of Language* 193/194, 139-160.

Warren, R. M. (2006). The relation of speech perception to the perception of nonverbal auditory patterns, in S. Greenberg & W. Ainsworth (eds.), *Listening to Speech: An Auditory Perspective*, Erlbaum, Mahwah, 333–349.

Weinreich, U., Labov, W., and Herzog, M. (1968). Empirical foundations for a theory of language change. In Lehmann, W. and Malkiel, Y. (eds.), *Directions for Historical Linguistics*. Austin: University of Texas Press, 97-195.

Notes

1. However, as a reviewer notes, it should be kept in mind that an anti-phase relationship corresponds to the planned voiceless fricative + stop sequence.

2. The ESPS/Waves algorithm is based on computing the normalized cross-correlation function (NCCF) at low and high samples rates of the speech signal and then using dynamic programming to select the set of NCCF peaks or unvoiced hypotheses (Talkin, 1995). The purpose of using dynamic programming is to incorporate continuity constraints across adjacent frames to reduce pitch doubling and halving errors. The algorithm is also based on a two-state voiced/unvoiced classification. By contrast, the algorithm in Scheffers (1983) is based on finding auditorily weighted harmonics in FFT spectra and uses a so-called harmonic sieve to identify components that bear a harmonic relation to one another. The reason why the two pitch algorithms perform differently has not yet been systematically investigated. It is possible for the present data that the ESPS/Waves algorithm performed less accurately in detecting the offset of periodicity in the closure because "in these cases... high correlations may be observed that can lead to an incorrect voicing decision" (Talkin, 1995). Other factors may be due to the use dynamic programming in the ESPS/Waves algorithm which might over-estimate the duration for which successive frames in the closure are voiced or because the binary voiced vs. unvoiced detection is less accurate in detecting the cessation of voicing for very low amplitude, quasi-periodic signals that typically occur during the closure.

3. In order to assess the reliability of the automatic measurements for *VTT* and *VOT* in *ht*-words, we compared these values with the manually measured data for pre- and post-aspiration that had been obtained for earlier versions of this paper. In the manual measurements the onset of *pre-aspiration* was marked at the point at which the energy of the second and third formants decreased clearly, together with the appearance of aperiodic noise in the waveform. The *post-aspiration* phase extended from the release of the stop to the onset of the first periodic waveform. The mean difference between manually measured and automatically measured durations was 1.1 ms (sd = 13.9 ms) for *VTT* (i.e. pre-aspiration), and 8.0 ms (sd = 5.5 ms) for *VOT* (i.e. post-aspiration). The difference in *VOT* came about because in the manual technique we took the onset of observable *periodic voicing* to be the offset of post-aspiration, while the automatic procedure was based on the onset of *voicing* (thereby potentially including some

aperiodic, low-amplitude periods which were not included manually). Mixed models with age and variety as fixed factors and word and speaker as the random factors were run on the token-wise difference between the automatic and the manual measures for *VOT* and *VTT*. The models showed no effect of the fixed factors on the dependent variable, which suggests that the manual and the automatic measurements performed no differently neither within nor between the groups.

4. As a reviewer notes, this finding has to be interpreted with caution because younger WAS speakers compared to older WAS speakers also showed slightly shorter closure durations in *t*-words.

5. The fitted GLMM calculated for each listener a logistic equation $p = e^{(mx + k)} / (1 + e^{(mx + k)})$, where p is the proportion of *pasta* (or *pata*) responses, x is the step number of the continuum ($x = 1, 2, ...10$), and in which m and k are the speaker-specific slope and intercept respectively. The 50% decision boundary is the x-value for which $p = 0.5$ which is given by $x = -k/m$.

6. The results have to be interpreted with the caveat that the test was conducted as a web-experiment and the listening conditions could therefore not be strictly controlled. Statistical tests were run in order to check whether the type of headphones/loudspeakers could have influenced the results. These showed that wearing (58/64 subjects) vs. not wearing (6/64 subjects) ear-/headphones had no significant effect on the results.

Figure captions

Figure 1

Waveform and spectrogram of the production of *estaba*. $V_{1.i}$ and $V_{1.f}$ are the acoustic onset and offset of the word-initial vowel, $V_{2.i}$ is the acoustic onset of /a/. The acoustic onset and offset of the closure are c_i and c_f respectively. *VTT* is defined as $c_i - V_{1.f}$ and *VOT* as $V_{2.i} - c_f$.

Figure 2

Distribution of voice termination time (*VVT*) in *ht*-words and in *t*-words in older and younger East Andalusian speakers and in older and younger West Andalusian speakers. Each boxplot consists of one (averaged) value per speaker on this measure. The rectangles span the interquartile range and the dot in the centre of the rectangle is the median of the distribution.

Figure 3

Distribution of the closure durations in older and younger East and West Andalusian speakers in *ht*-words and in *t*-words. Each boxplot consists of one averaged value per speaker on this measure.

Figure 4

Distribution of voice onset time (*VOT*) in *ht*-words and *t*-words in the four speaker groups. Each boxplot consists of one averaged value per speaker on this measure.

Figure 5

Scatter plots of the duration of post-aspiration (*VOT*; y-axis) in *ht*-words as a function of pre-aspiration duration (*VVT*; x-axis) for West (row 1) and East (row 2) Andalusian speakers and for older (left) and younger (right) speakers.

Figure 6

Scatter plots of the duration of pre-aspiration (*VTT*; y-axis) in *ht*-words as a function of closure duration for West (row 1) and East (row 2) Andalusian speakers and for older (left) and younger (right) speakers.

Figure 7

Scatter plots of the duration of post-aspiration (*VOT*; y-axis) in *ht*-words as a function of closure duration (x-axis) for West (row 1) and East (row 2) Andalusian speakers and for older (left) and younger (right) speakers.

Figure 8
Speaker-specific slopes derived after fitting a mixed model to the data in Fig. 7 for the four speaker groups. Each boxplot consists of one slope value per speaker.

Figure 9
Proportions of listeners' judgements as either *pasta* (black) or *pata* (grey) on the stimuli of two *VTT*-continua, separated by stimulus number (0: *VTT* = 0 ms, 9: *VTT* = 34 ms) and *VOT* (*long* = 29 ms, *short* = 12 ms).

Figure 10
Ensemble-averaged fitted psychometric curves showing the mean proportion of *pata* responses as a function of the stimulus number in forced-choice *pasta-pata* perception tests. The solid/dashed lines represent the responses from the same 57 Argentinian listeners to the two continua synthesised with a long/short VOT in /t/ respectively. The stimulus numbers 0 to 9 extend in equal steps between a *VTT* of 0 to 34 ms.

Figure 11
The distribution (one value per listener) of the difference between the *long* and the *short* decision boundaries for the data shown in Fig. 10.

Table

Table I

	East Andalusian						West Andalusian						Σ
	Younger			Older			Younger			Older			
Group/Label	st	ht	0t	st	ht	0t	st	ht	0t	st	ht	0t	
1 (higher zcr)	14	0	0	14	**1**	**1**	9	0	0	17	0	0	56
2 (lower zcr)	**2**	50	24	**7**	64	17	**1**	24	37	**11**	51	24	312
3 (VTT < 5 ms)	0	1	35	0	0	17	0	2	17	0	6	55	133
Σ	16	51	59	21	65	35	10	26	54	28	57	79	501

Table I: Comparison between auditory labels (colums; st, ht, 0t) and automatic classification (rows; groups 1, 2, 3). The first two rows include the numbers of tokens (in *estaba, estado, estanco, pestaña*) for which $c_i > V_{1,f}$ (i.e. voicing ended before closure beginning) separated into two groups by *k*-means clustering. The third row shows the numbers of tokens in the same words not analysed by *k*-means clustering for which $c_i < V_{1,f}$. The numbers are broken down by variety, age-group, and auditory label. Numbers in bold are those in which the automatic and auditory analyses disagreed (in which /st/, produced according to the auditory analysis with a full alveolar fricative, was assigned to group 2; or in which /st/, produced according to the auditory analysis with pre-aspiration or an elided syllable final /s/, was included in group 1). All 56 tokens in group 1 were discarded from further analysis.

Table II

Variety	East Andalusian		West Andalusian		Σ
Category/Age group	Younger	Older	Younger	Older	
ht-words	112	105	81	147	445
t-words	69	61	65	62	257
Σ	181	166	146	209	702

Table II: The first row (*ht*-words) shows the number of remaining tokens in *estaba, estado, estanco, pestaña* that were included in the analysis (these are the sums of rows 2 and 3 in Table I) by age group and variety. The second row (*t*-words) shows the distribution of tokens in *etapa* and *retara* that were also analysed.

Table III

Variety	East Andalusian				West Andalusian			
Category/Age group	Younger		Older		Younger		Older	
VVT **(ms)**								
ht-words	10.3	13.2	18.3	19.0	5.6	10.7	17.8	20.6
t-words	-10.0	22.2	-5.0	19.4	-11.6	17.5	-10.2	20.1
Closure duration **(ms)**								
ht-words	113.4	26.2	115.2	23.8	88.7	20.3	110.0	22.3
t-words	80.4	17.1	81.0	18.5	68.9	16.9	81.1	17.7
VOT **(ms)**								
ht-words	35.8	14.0	20.4	8.1	55.2	17.5	26.8	10.3

t-words	18.7	6.4	16.3	7.5	18.7	7.4	19.2	11.5

Table III: Mean values (grey shadowed colums) and standard deviation in ms of voice termination time (*VTT*), closure duration and voice onset time (*VOT*) for each speaker group.

Table IV

	Short-continuum			**Long-continuum**		
step	*VTT*	Closure duration	*VOT*	*VTT*	Closure duration	*VOT*
0	0	100 ms	12 ms	0	100 ms	29 ms
1	5			5		
2	12			12		
3	16			16		
4	19			19		
5	22			22		
6	25			25		
7	29			29		
8	32			32		
9	34			34		

Table IV. *VTT*, *VOT* and closure duration values (ms) of the stimuli used in the *pasta*/*pata*-perception experiment.

Figure1

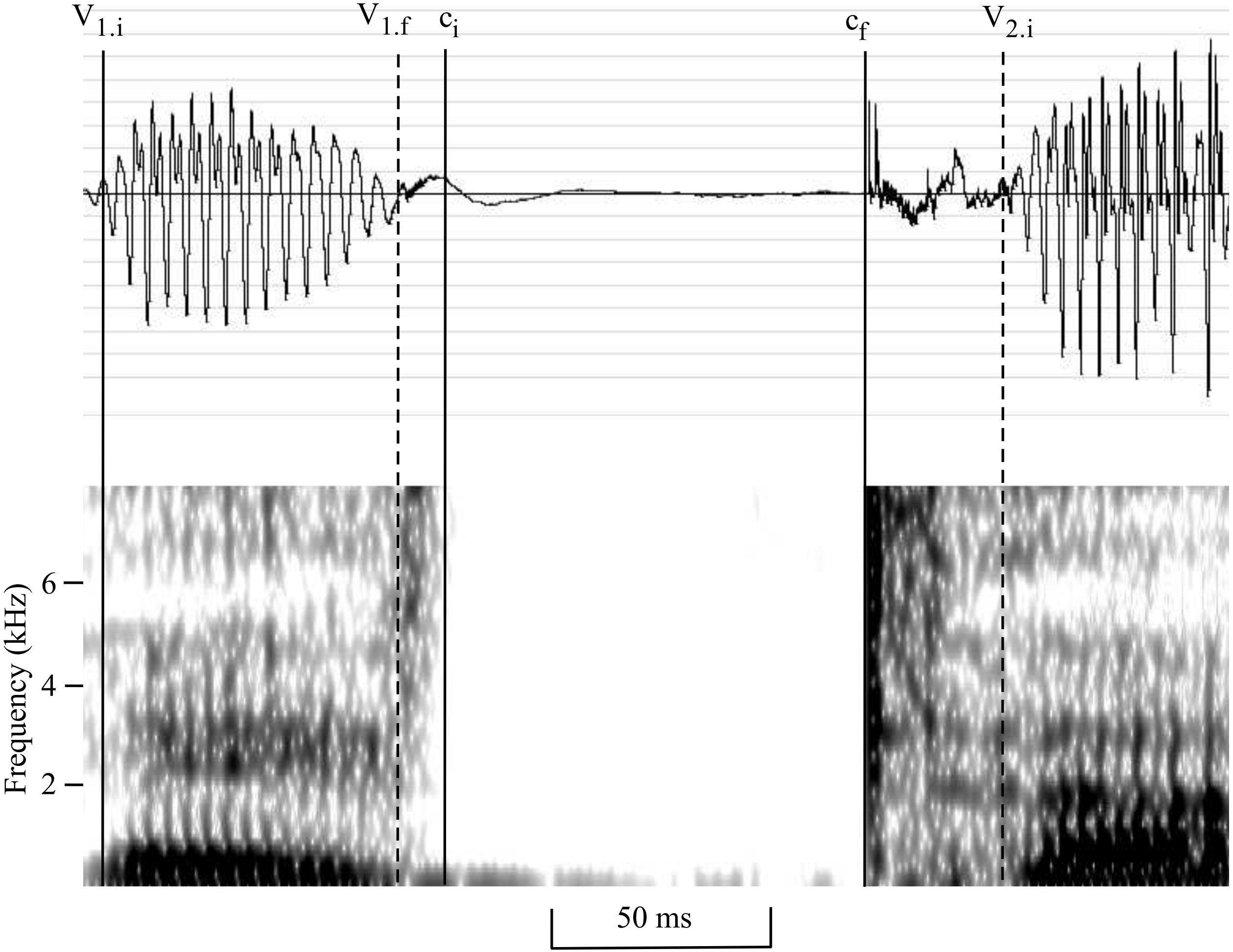
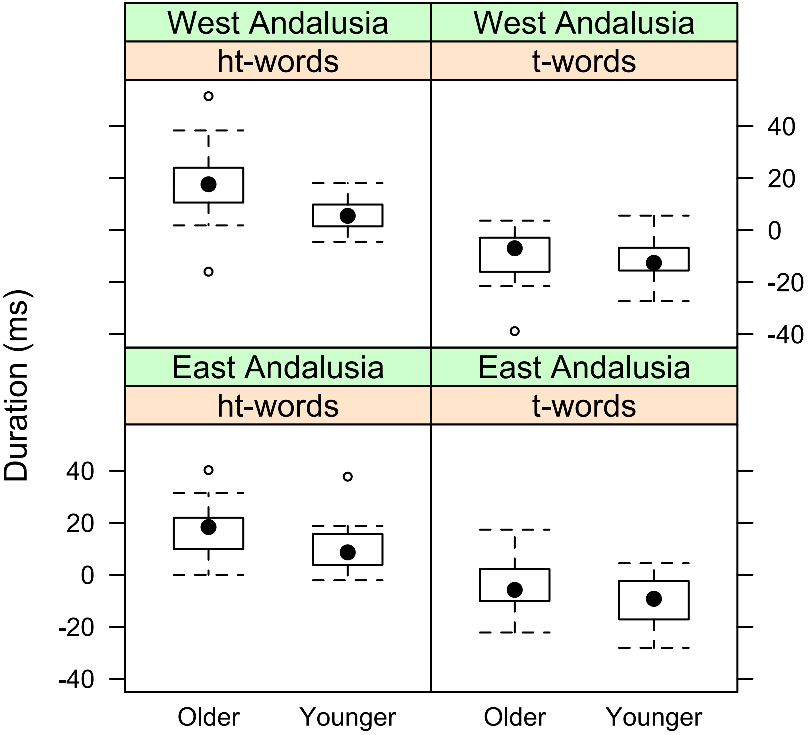


Figure2



West Andalusia
ht-words
West Andalusia
t-words
East Andalusia
ht-words
East Andalusia
t-words
Duration (ms)
40
20
0
-20
-40
Older
Younger
Older
Younger

Figure3

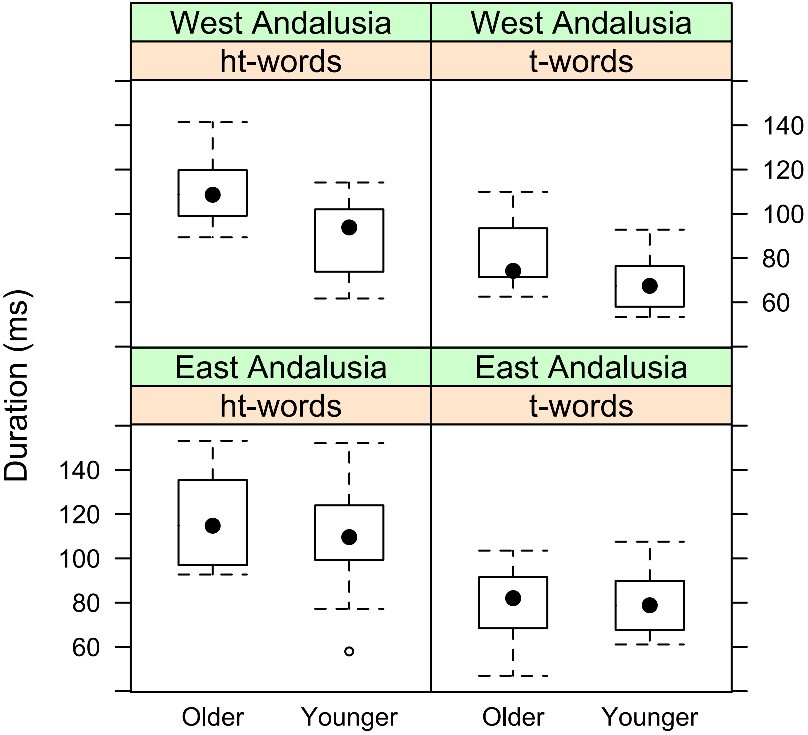
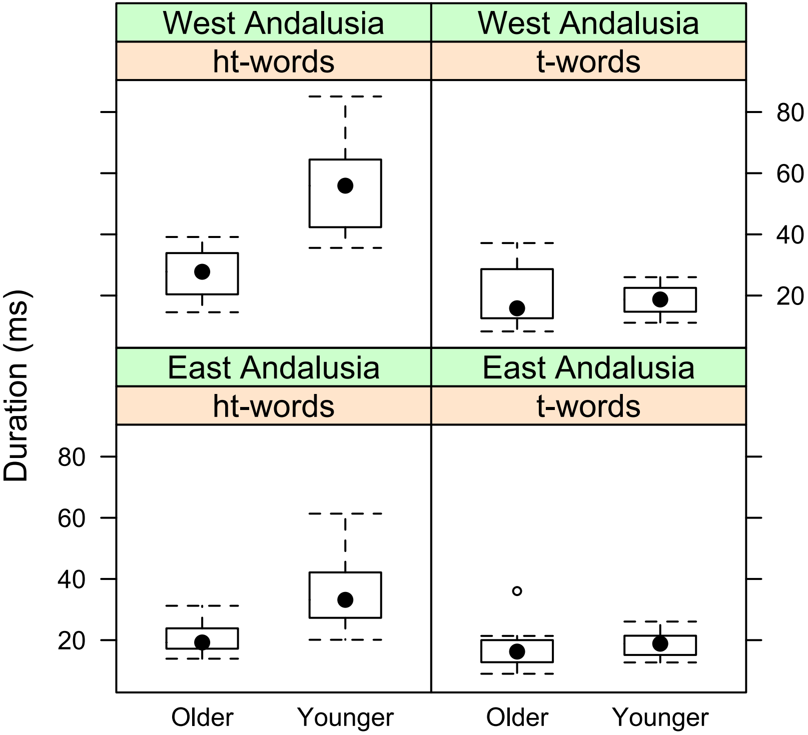

West Andalusia
ht-words
West Andalusia
t-words
East Andalusia
ht-words
East Andalusia
t-words
Duration (ms)
140
120
100
80
60
Older
Younger
Older
Younger

Figure4



West Andalusia
ht-words
West Andalusia
t-words
East Andalusia
ht-words
East Andalusia
t-words
Duration (ms)
80
60
40
20
Older
Younger
Older
Younger

Figure5

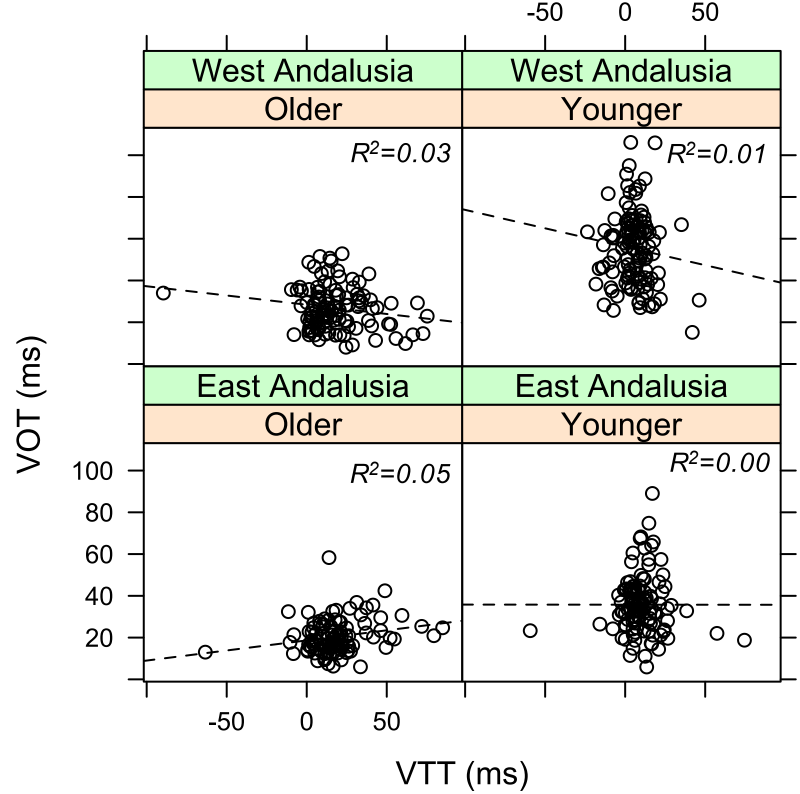

West Andalusia
Older
West Andalusia
Younger
East Andalusia
Older
East Andalusia
Younger
R²=0.03
R²=0.01
R²=0.05
R²=0.00
-50
0
50
100
80
60
40
20
VOT (ms)
VTT (ms)

Figure6

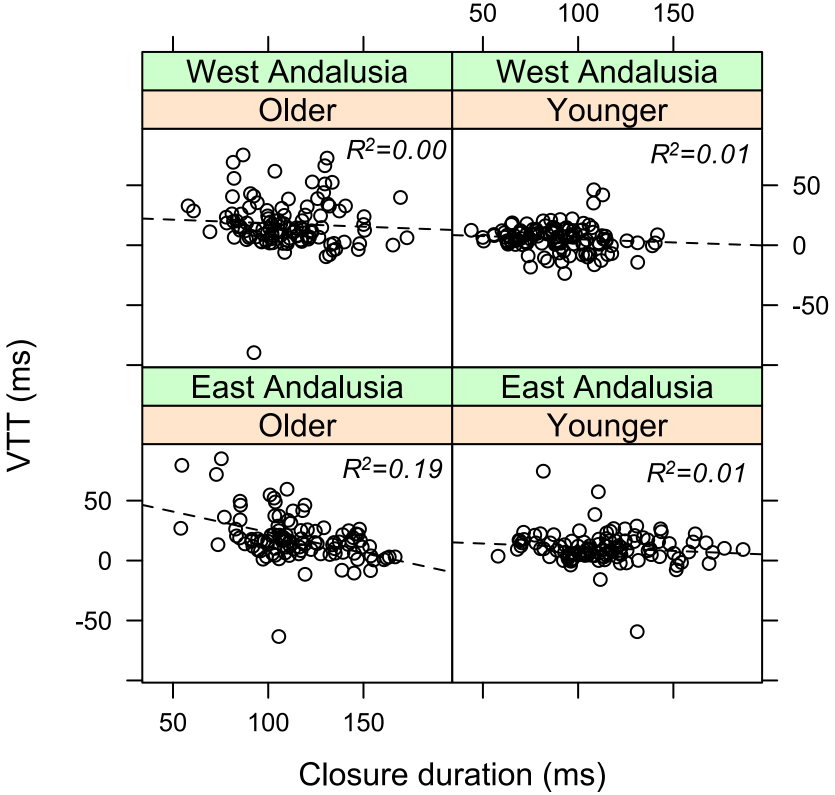

West Andalusia
Older
R^2=0.00
West Andalusia
Younger
R^2=0.01
East Andalusia
Older
R^2=0.19
East Andalusia
Younger
R^2=0.01
50
100
150
50
0
-50
VTT (ms)
Closure duration (ms)

Figure7

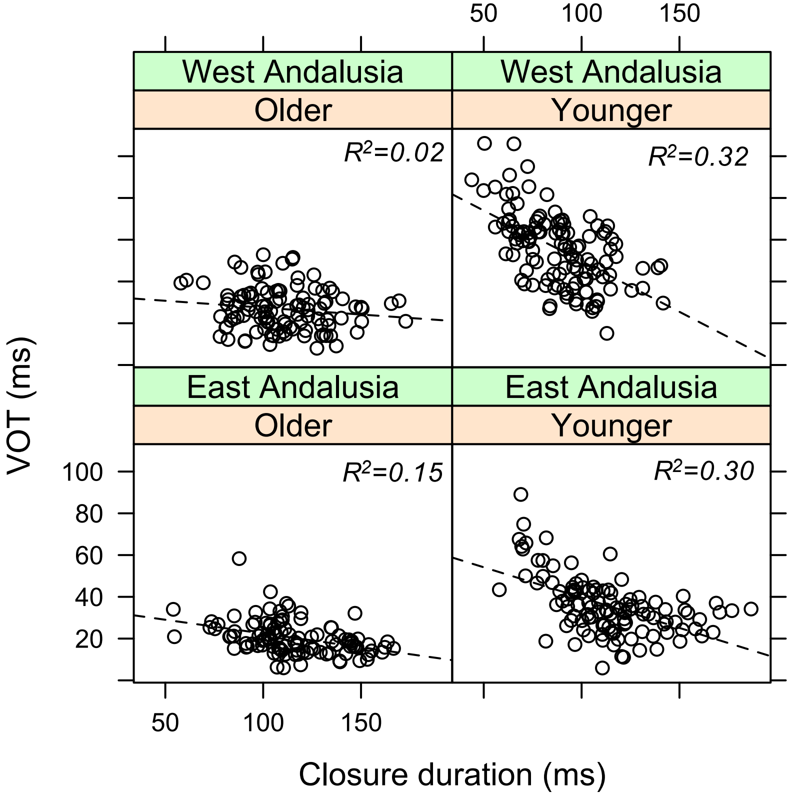

West Andalusia
Older
R^2=0.02
West Andalusia
Younger
R^2=0.32
East Andalusia
Older
R^2=0.15
East Andalusia
Younger
R^2=0.30
VOT (ms)
Closure duration (ms)
50
100
150
20
40
60
80
100

Figure8

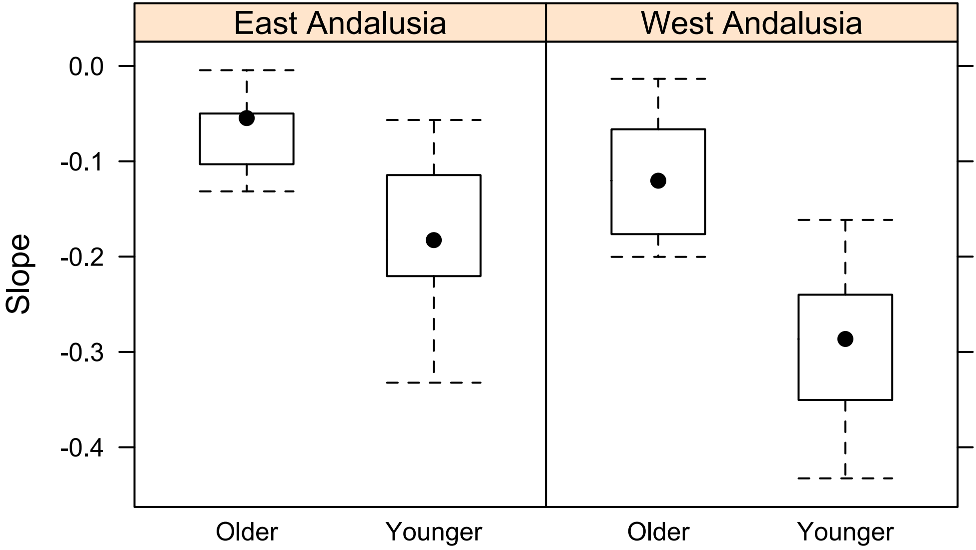

East Andalusia
West Andalusia
0.0
-0.1
-0.2
-0.3
-0.4
Slope
Older
Younger
Older
Younger

Figure9

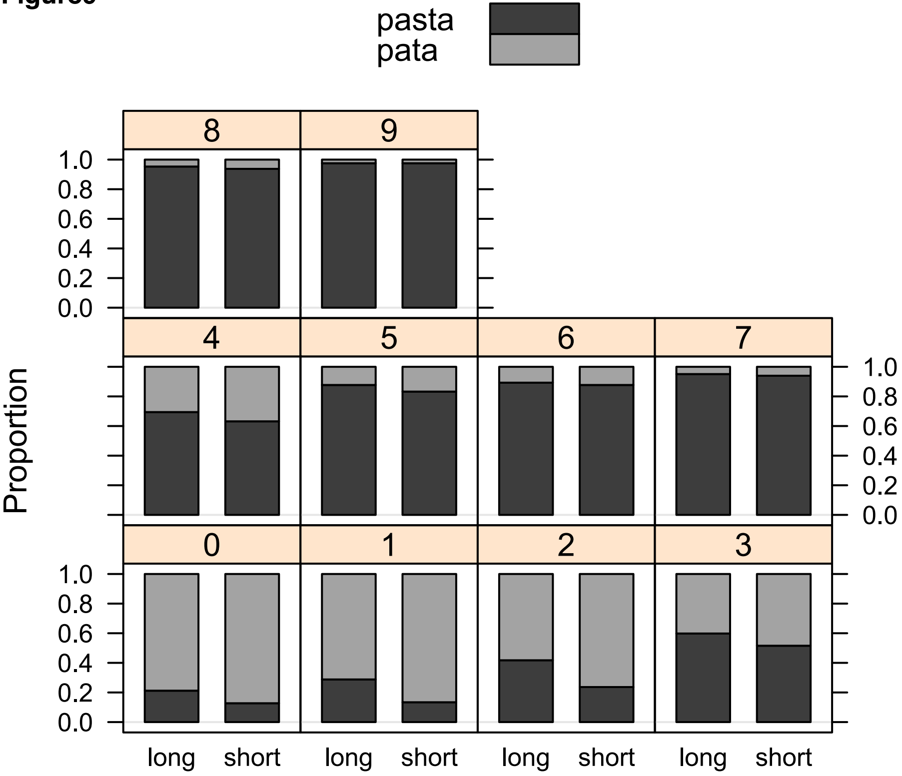

pasta
pata
8
9
4
5
6
7
0
1
2
3
1.0
0.8
0.6
0.4
0.2
0.0
Proportion
long
short

Figure10

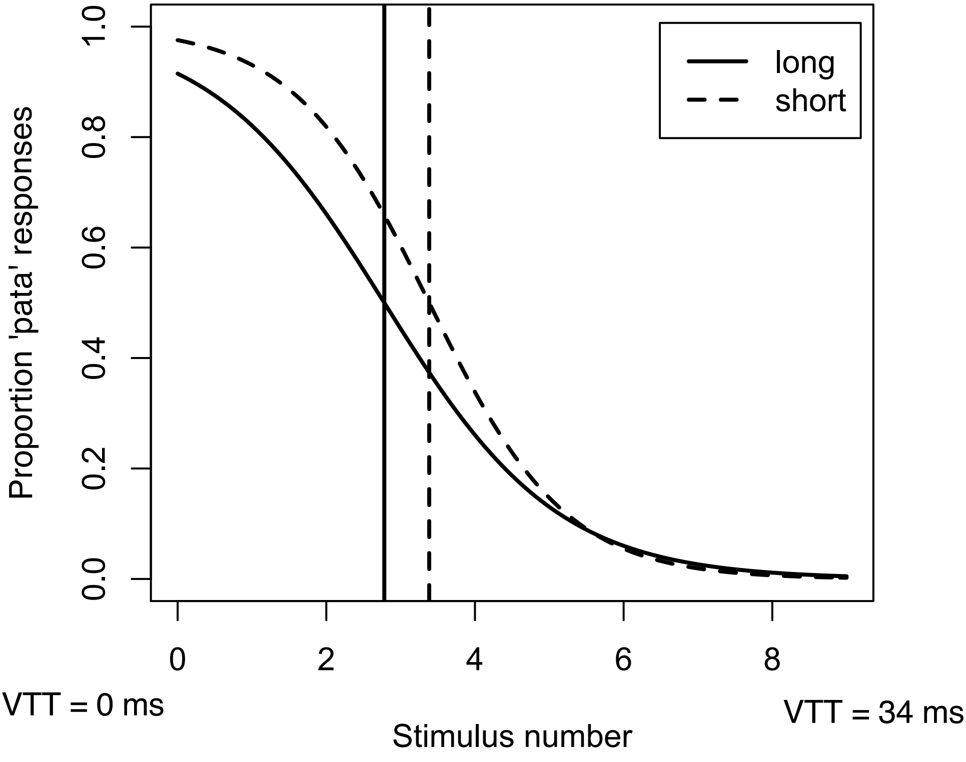

1.0
0.8
0.6
0.4
0.2
0.0
Proportion 'pata' responses
long
short
0
2
4
6
8
VTT = 0 ms
VTT = 34 ms
Stimulus number

Figure11